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Ng, C-H., Chan, C. W., Man, H-C., Waugh, D., Lawrence, J., & Smith, G. (2015). *Novel Laser Technology to Enhance the Wear Resistance of Shape Memory NiTi Alloy for Total Joint Replacement Applications*. Poster session presented at Journey through Science Day (hosted by PepsiCo and the New York Academy of Science, NYAS), New York, United States.

Document Version:
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Download date:05. May. 2023

Novel Laser Technology to Enhance the Wear Resistance of Shape Memory NiTi Alloy for Total Joint Replacement Applications

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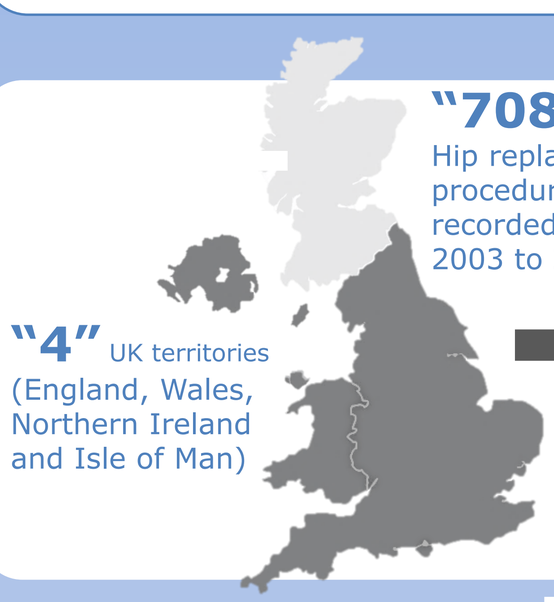
Introduction



"4" UK territories (England, Wales, Northern Ireland and Isle of Man)

"708,311" Hip replacement procedures were recorded from 2003 to 2014[1]

- Primary Operation (90 %)
- **Revision Operation (10 %)**

Reasons Why Implants are Replaced

- Within **1st** year, the most common reasons: dislocation, fracture or infection
- After **5th** year, the most common reason: aseptic loosening, pain or wear

Implant Failure Rate for Revision[1]

1. Aseptic Loosening (50.0 %)
2. Pain (23.1 %)
3. **Wear (13.6 %)**
4. Dislocation (12.9 %)
5. Facture (11.9 %)
6. Infection (9.0 %)

Wear contributed **"13.6 %"** for implant failure (2003 -2014) [1]

Laser Gas Nitriding

1. Selective Area Processing
2. Fast and Clean
3. Non-Contact Method

Experiments

Two Stage of Laser Experiments

STAGE 1

Preliminary Parameter Study

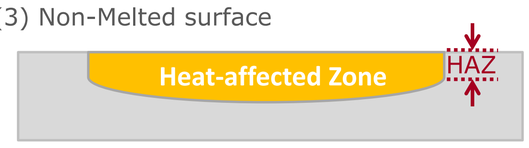
- Taguchi Method (Design of Experiments)
- Parameters for Laser Diffusion Nitriding

Power (W)	Scanning Speed (mm/min)	Beam Diameter (mm)
80 - 100	60 - 240	1.1 - 2.2

STAGE 2

Optimized Laser Process

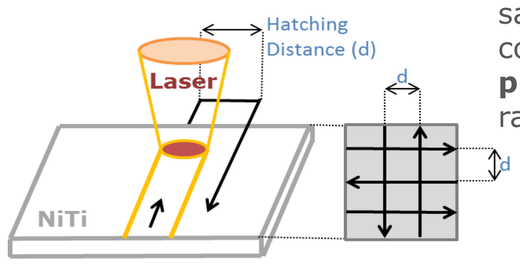
(1) Good Uniformity
(2) Minimize Heat Affected Zone
(3) Non-Melted surface



Minimized HAZ

Laser Machine

SPI CW 100W Fibre Laser
(Wavelength: 1091 nm)



Laser Gas Nitriding

Laser nitriding process was carried out using the **CW fiber laser.** The sample was purged with a continuous supply of **high purity nitrogen** at a flow rate of **30 L/min.**

Sample 1: d = 3.0 mm
Sample 2: d = 1.0 mm
Sample 3: d = 0.2 mm

Microstructural Characterization

(1) Optical Microscopy (OM):
Preliminary observation of the surface appearance

(2) Scanning Electron Microscopy (SEM):
Examination of the cross-sectioned surface

(3) X-ray Diffraction (XRD):
Identification of the phases present in the surface

Research Objective

To improve the wear resistance of shape memory NiTi alloy and to reduce the processing time by "Selective Laser Gas Nitriding"
(To change the coverage ratio of TiN on laser-nitrided surface)

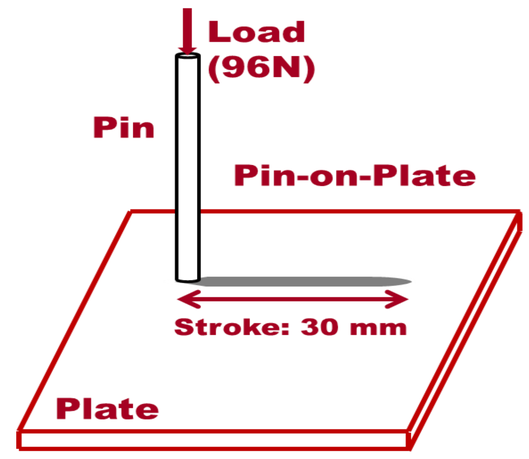
Wear Resistance Measurement

Reciprocating Pin-on-Plate Test

Samples against an **ultra-high-molecular-weight polyethylene (UHMWPE)** pin of **8 mm** diameter

Testing Conditions

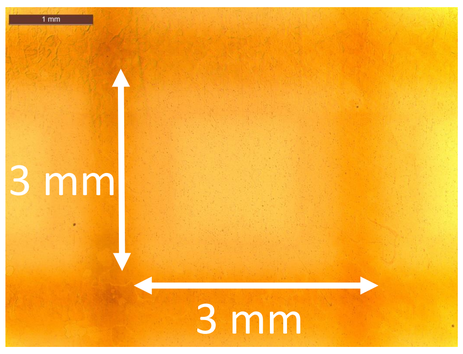
Frequency of **2 Hz**, with a stroke length of **30 mm**, the test duration being set at **172,800 cycles** (about **10 km** of sliding distance)



Setup of Reciprocating Sliding Test

Results and Discussions

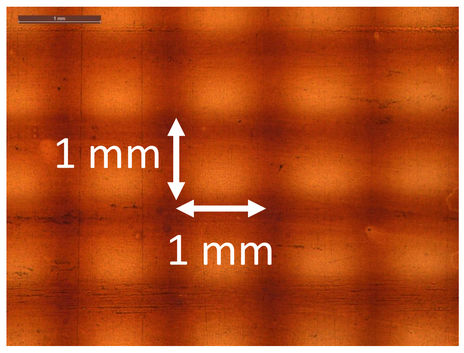
Surface Appearance



Sample 1
Laser Nitrided Surface with **"52 %"** of TiN coverage

Optimised Laser Parameter

Power	Scanning Speed	Focal Spot Size
90 W	120 mm/min	2.2 mm

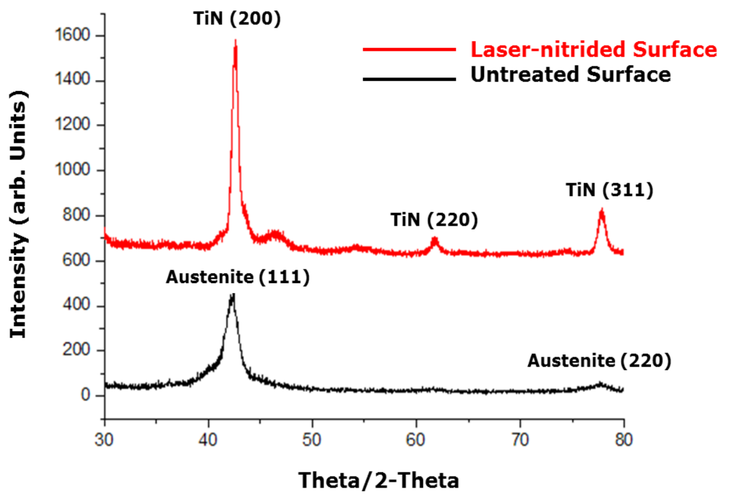


Sample 2
Laser Nitrided Surface with **"76 %"** of TiN coverage

TiN Coverage:

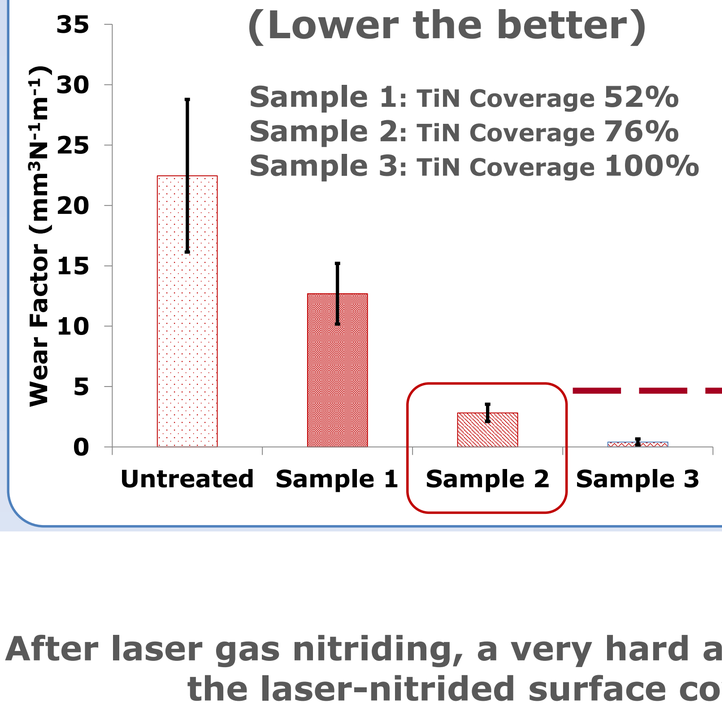
Sample 1 (52%) < Sample 2 (76%) < Sample 3 (100%)

Microstructural Characterization

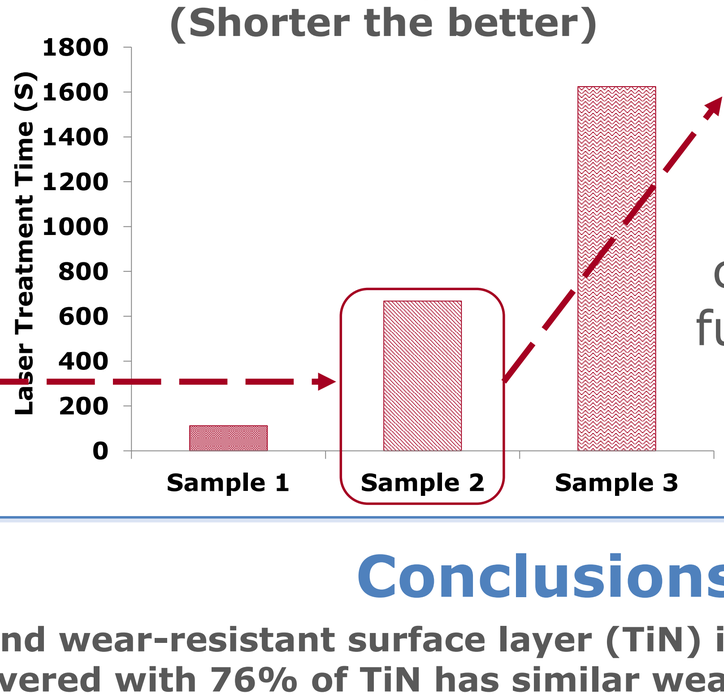


Wear Resistance

Wear Factor (Lower the better)

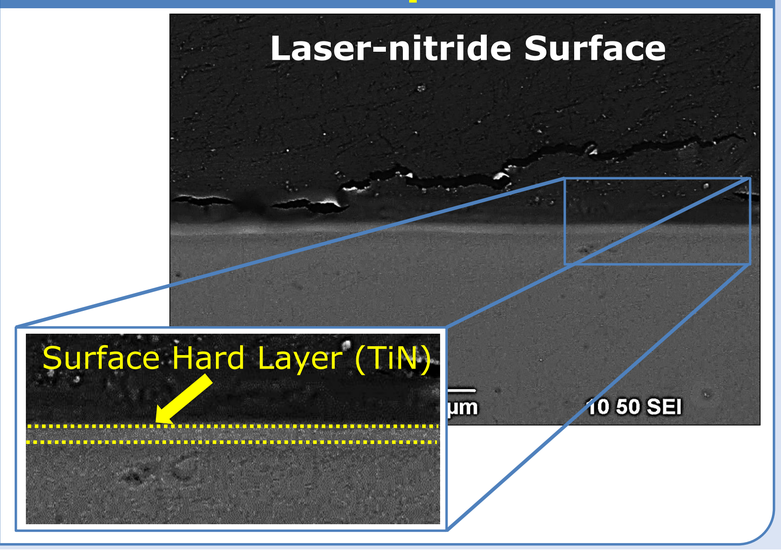


Processing Time (Shorter the better)



Save **"59 %"** treatment time compare to fully covered surface

Thickness of a uniform nitride layer ≈1.6μm



Conclusions

After laser gas nitriding, a very hard and wear-resistant surface layer (TiN) is fabricated in the NiTi sample. Our findings indicate that the laser-nitrided surface covered with 76% of TiN has similar wear resistance to that of the fully covered sample.

Reference:
[1] National Joint Registry 12th Annual Report 2015, National Joint Registry for England, Wales, Northern Ireland and the Isle of Man

Acknowledgment: Laser surface treatment and wear experimentations were done at the QUB, UK and the HKPolyU, HK, China. Surface characterization were done at the University of Chester, UK.